BaBar Tracking

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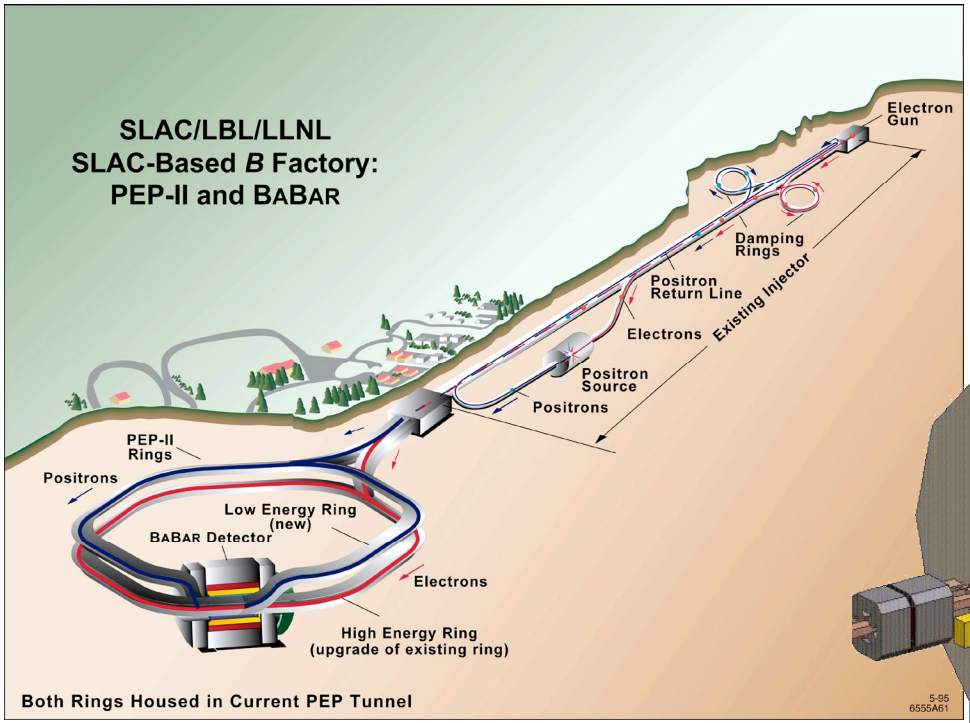
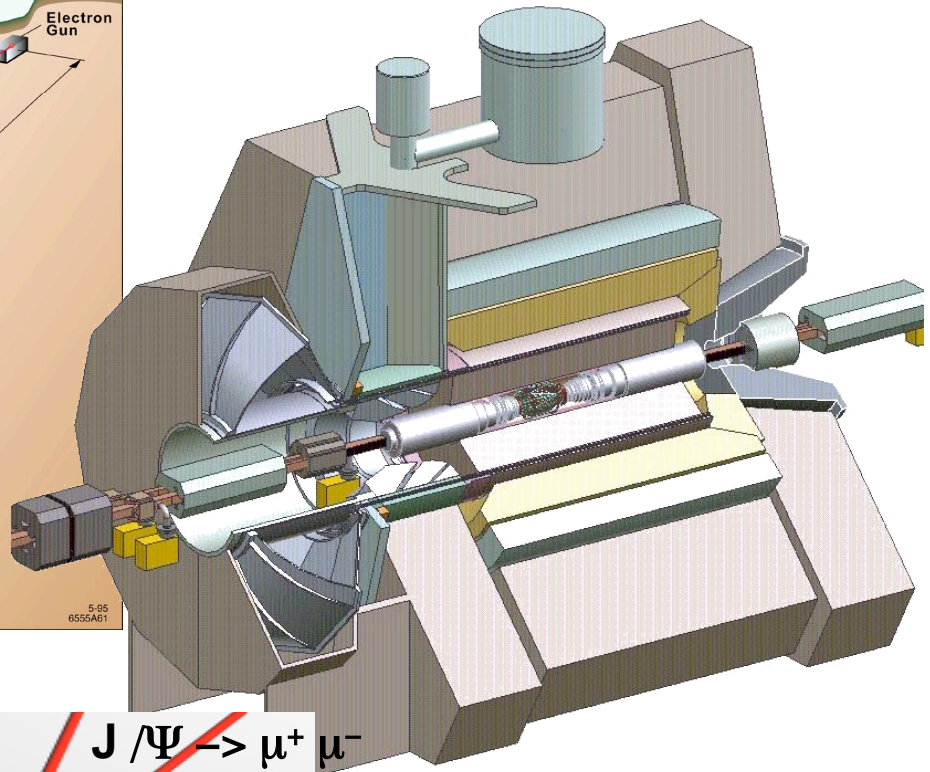
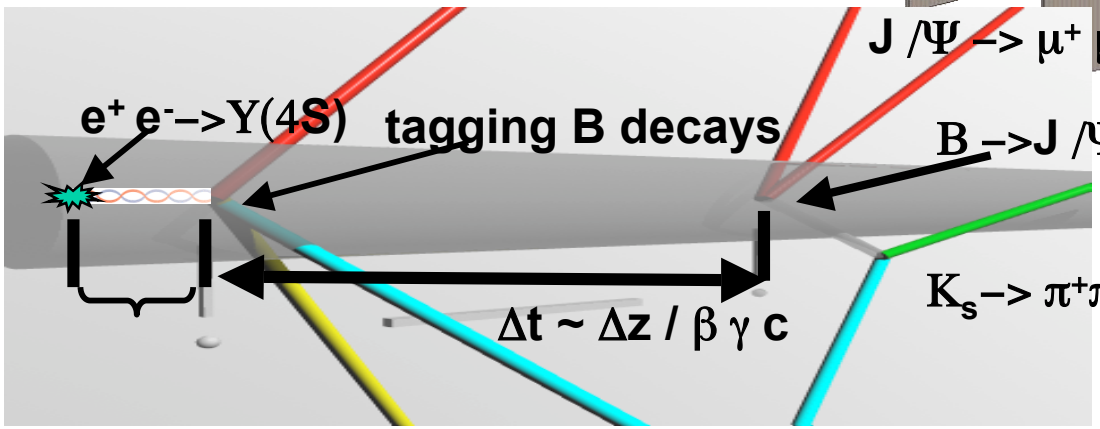
- **BaBar Overview**
- **BaBar Tracking Algorithms**
- **Kalman Fit and Extensions**
- **Current and Future Developments**

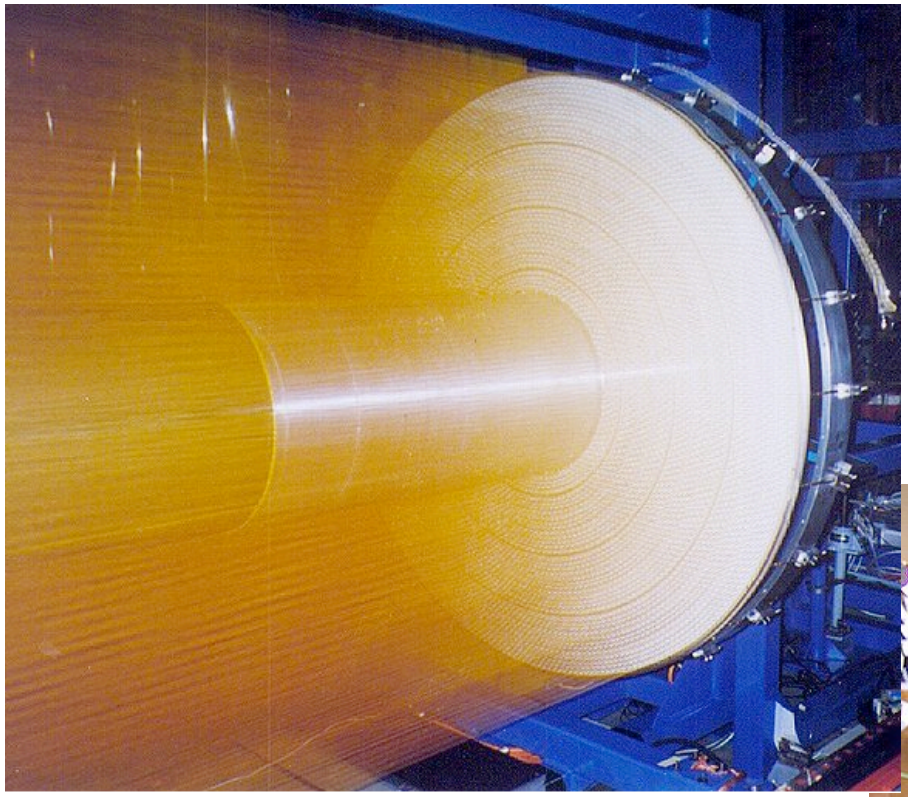
The BaBar Experiment



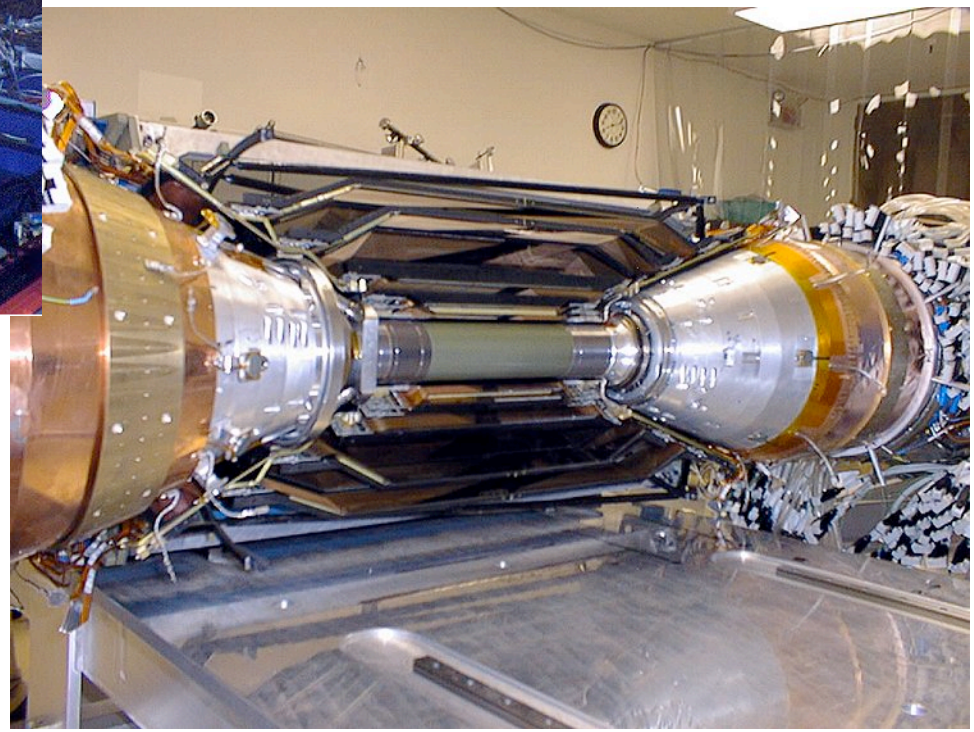




The BaBar Tracking Detectors

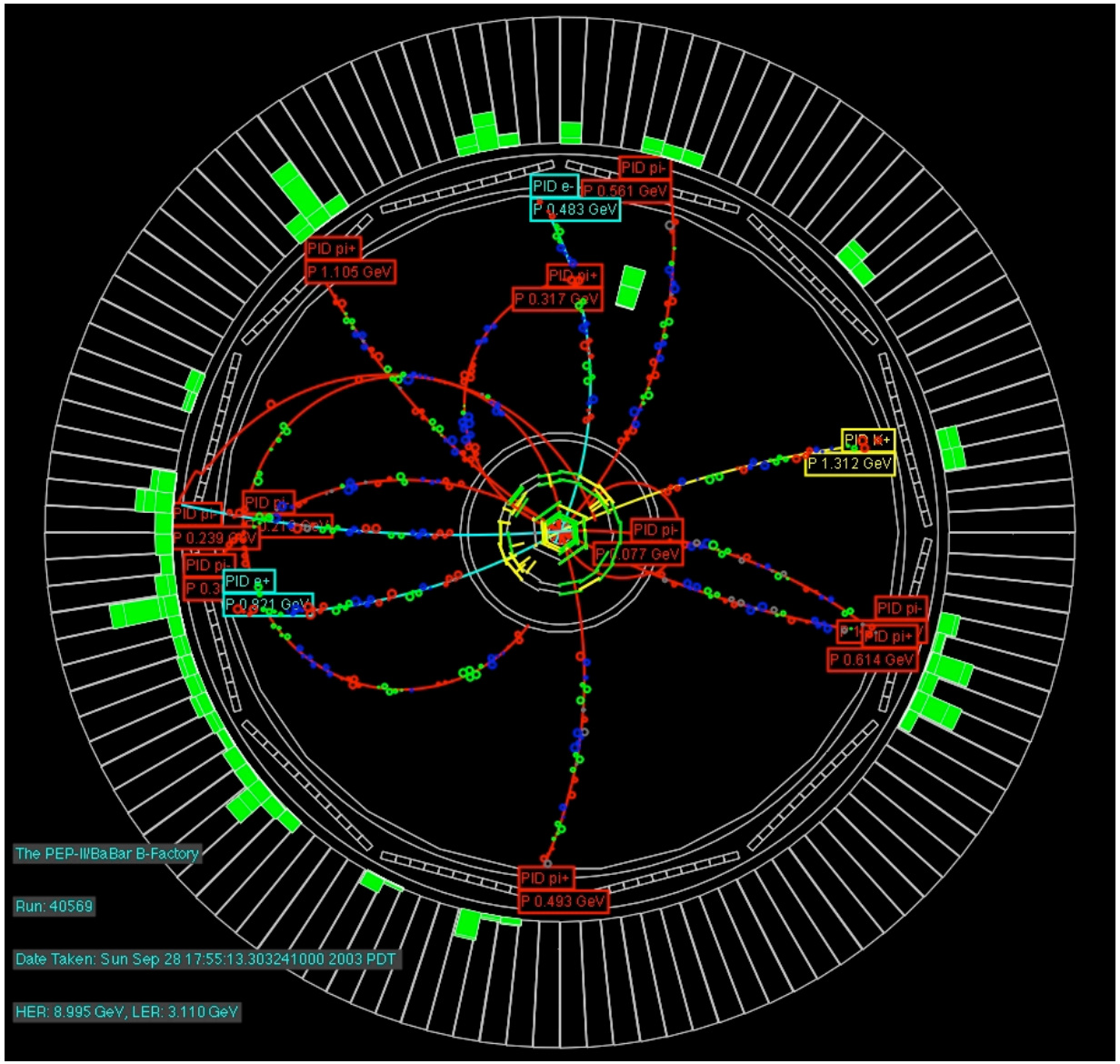


- 40-layer drift chamber
  - Axial and ± ~3° stereo layers
  - ~150 μm resolution
  - He-based gas
  - dE/dx for PID
- 1.5T Solenoidal BField



- 5-layer double-sided Si tracker
  - Low mass in active volume
  - ~10-20 μm hit resolution
  - Charge measurement (dE/dx)

Track uses in BaBar



- **Triggering**
- **Event kinematics**
- **Decay vertices**
- **PID**
  - **dE/dx**
  - **Extrapolation to outer detectors**

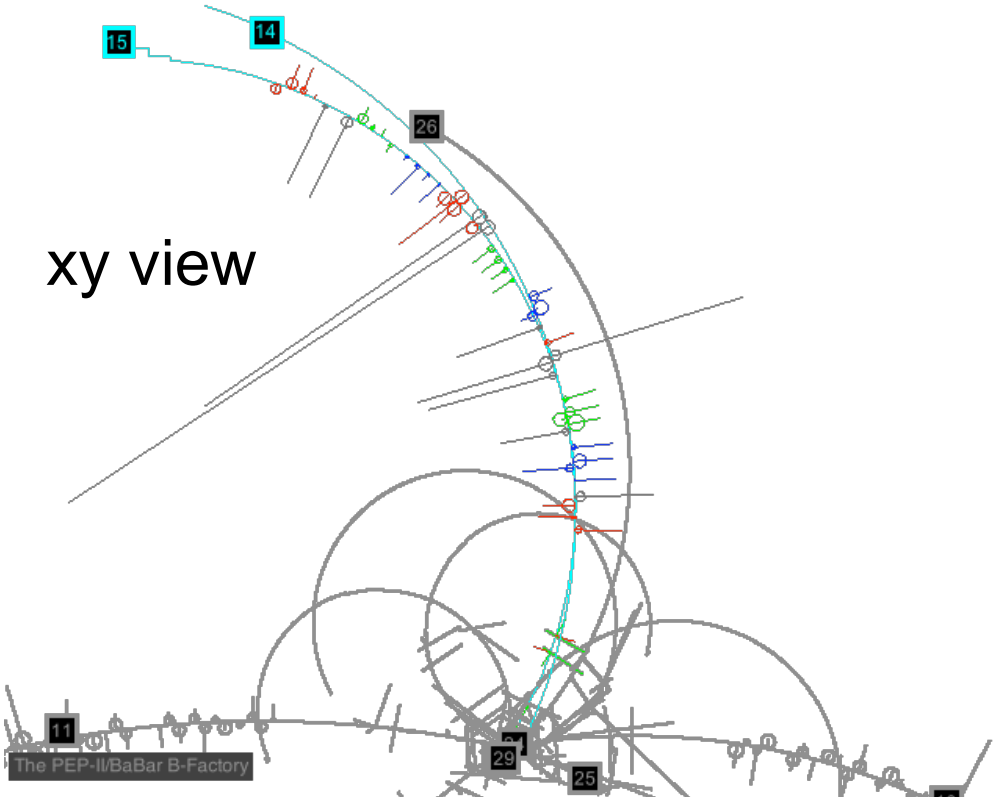
BaBar Tracking Sequence

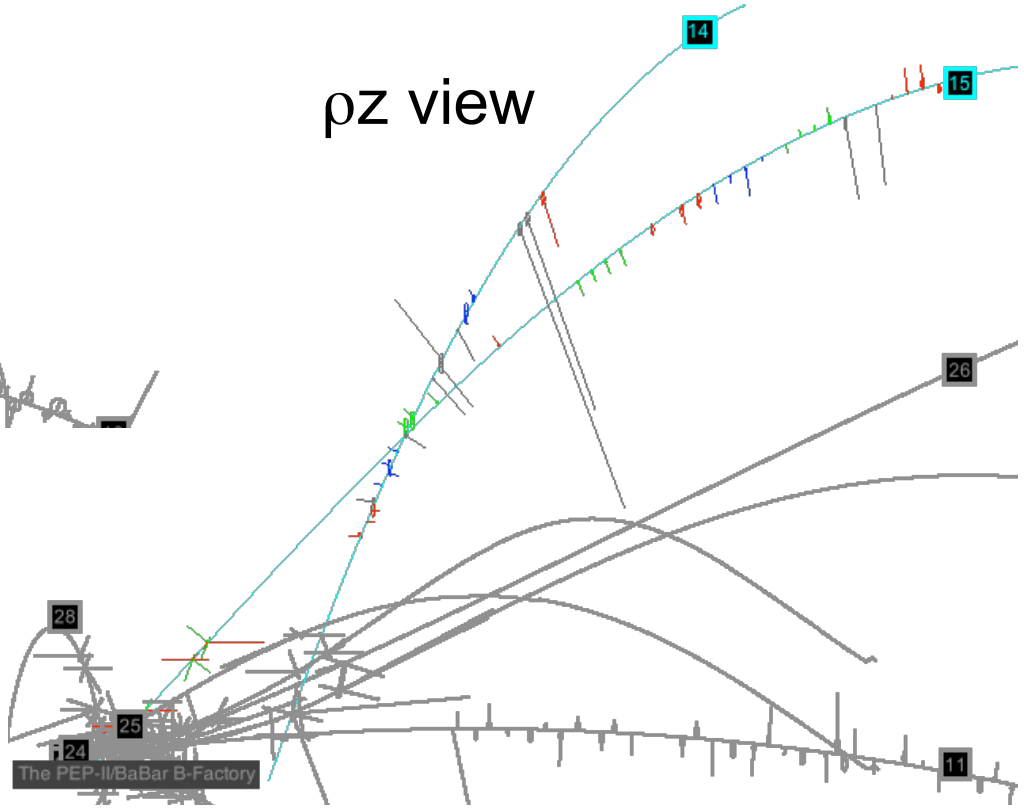
- **Standalone Drift Chamber (Dch) track finding**
  - ✦ **Simple least-squares fit**
  - ✦ **Tracks from several independent modules are combined**
- **Kalman fit of Dch tracks**
- **Extension of Dch Kalman fits into Si vertex (Svt)**
- **Standalone Svt track finding**
  - ✦ **Simple least-squares fit**
  - ✦ **Tracks from 2 independent modules are combined**
- **Kalman fit of Svt tracks**
- **Extension of Svt Kalman tracks into Dch**
  - ✦ **Recovers hits on low-pt tracks**

BaBar Track Finding

- **Drift chamber tracks using segment patterns**
  - ✦ **Online (trigger) track finding using hard-coded pattern rules**
  - ✦ **Offline uses more flexible patterns**
  - ✦ **Segment seeds are grown into helix fits**
- **Si tracks using hit triples**
  - ✦ **Space point tripples in low-hit-density environment**
  - ✦ **R-phi triples assume tracks from origin: conformal map**
    - ★ $\upsilon = x/(x^2+y^2)$, $\nu=y/(x^2+y^2)$ transforms circles through (0,0) to lines
- **Track Finding is the oldest reco code in BaBar**
  - ✦ **No coherent design**
    - ★ Fortran-style C++
  - ✦ **Incomplete debugging and optimization**
  - ✦ **Known performance problems**

Ghost Tracks



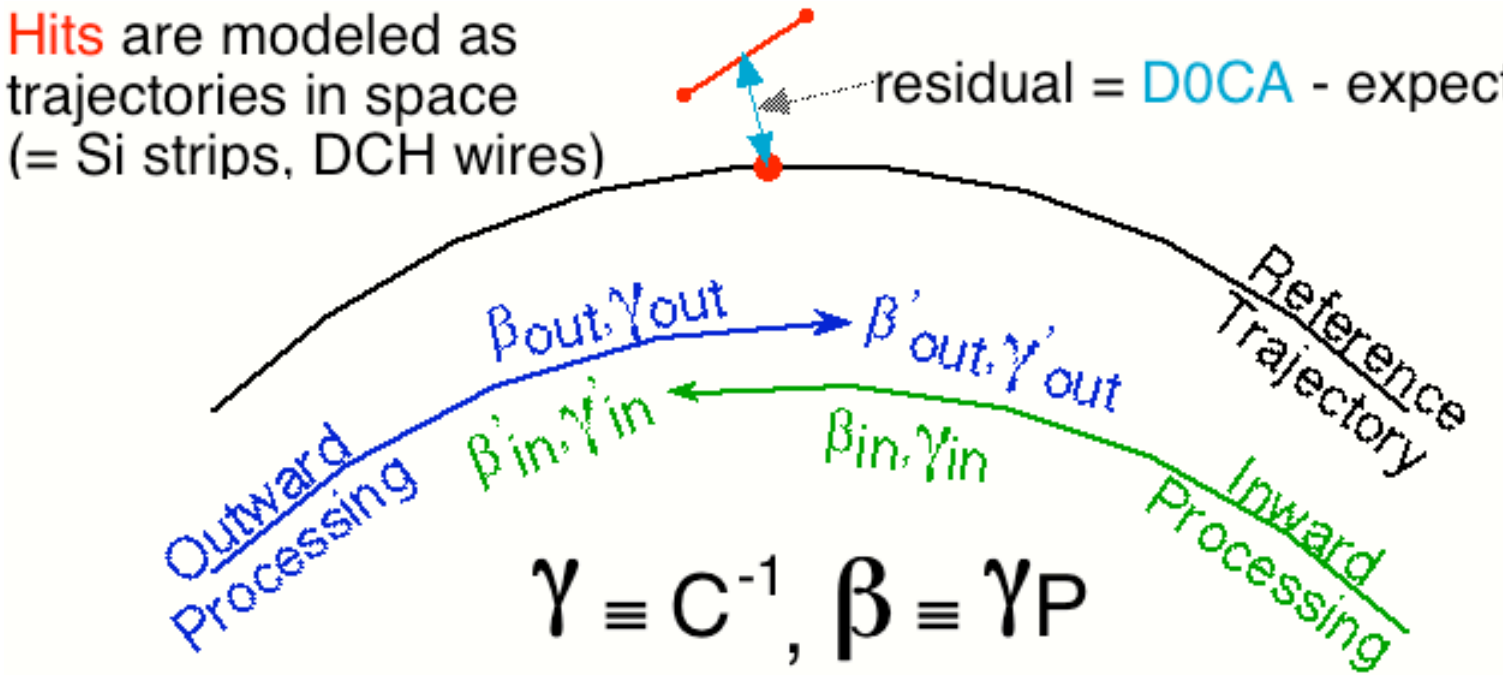


- **~5% of tracks are ghosts**
  - **impacts bkg, resolution**
- **Remediation after reco.**
  - **Analysis cuts**
  - **TrkFixup**

BaBar Kalman Fit

- **'Traditional' Kalman Fit formalisms**
  - **Weighted Means**
    - ★ Explicit progressive linear least squares
  - **Gain Matrix**
    - ★ Equivalent mathematically, faster and more stable numerically
- **BaBar uses a Hybrid, extended formalism**
  - **Use gain matrix where needed for speed, stability**
  - **Use weighted means where natural**
  - **Time ordering of 'information' is symmeterized**
    - ★ Simplifies algorithm
  - **Inner and outer track parameters treated the same**
    - ★ Allows a more rational software organization
    - ★ Appropriate for inner and outer track uses
  - **Fit output is a 1-dimensional object in 3 space**
    - ★ Not just parameters
- **5 stable mass hypothesis fit results**

Hit Effect (in Weight Space)



$$\gamma \equiv C^{-1},\ \beta \equiv \gamma P$$

$$\beta'_{out,in} = \beta_{out,in} + \overbrace{L^t (1/\sigma) (LR - r)}^{\equiv \beta_{hit}}$$

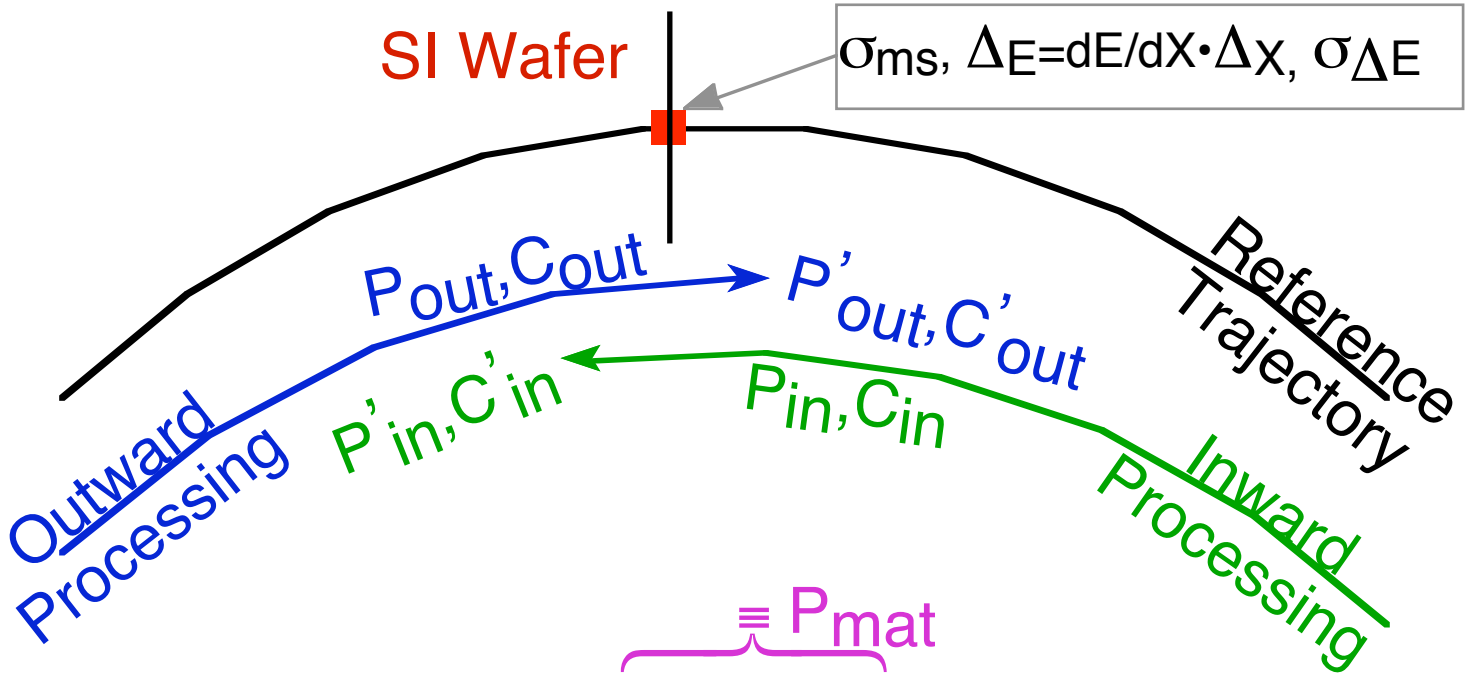
$$\gamma'_{out,in} = \gamma_{out,in} + \underbrace{L^t (1/\sigma)^2 L}_{\equiv \gamma_{hit}}$$

$\sigma \equiv$ hit error

$L \equiv \delta P/\delta r$

$R \equiv$ reference parameters

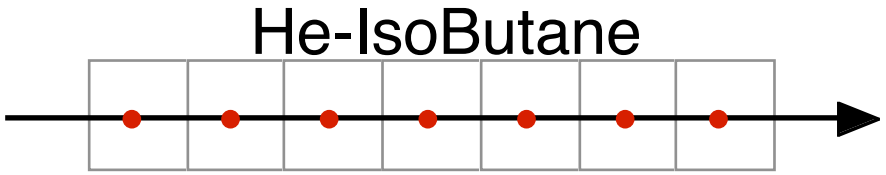
Material Effect



$\equiv P_{mat}$

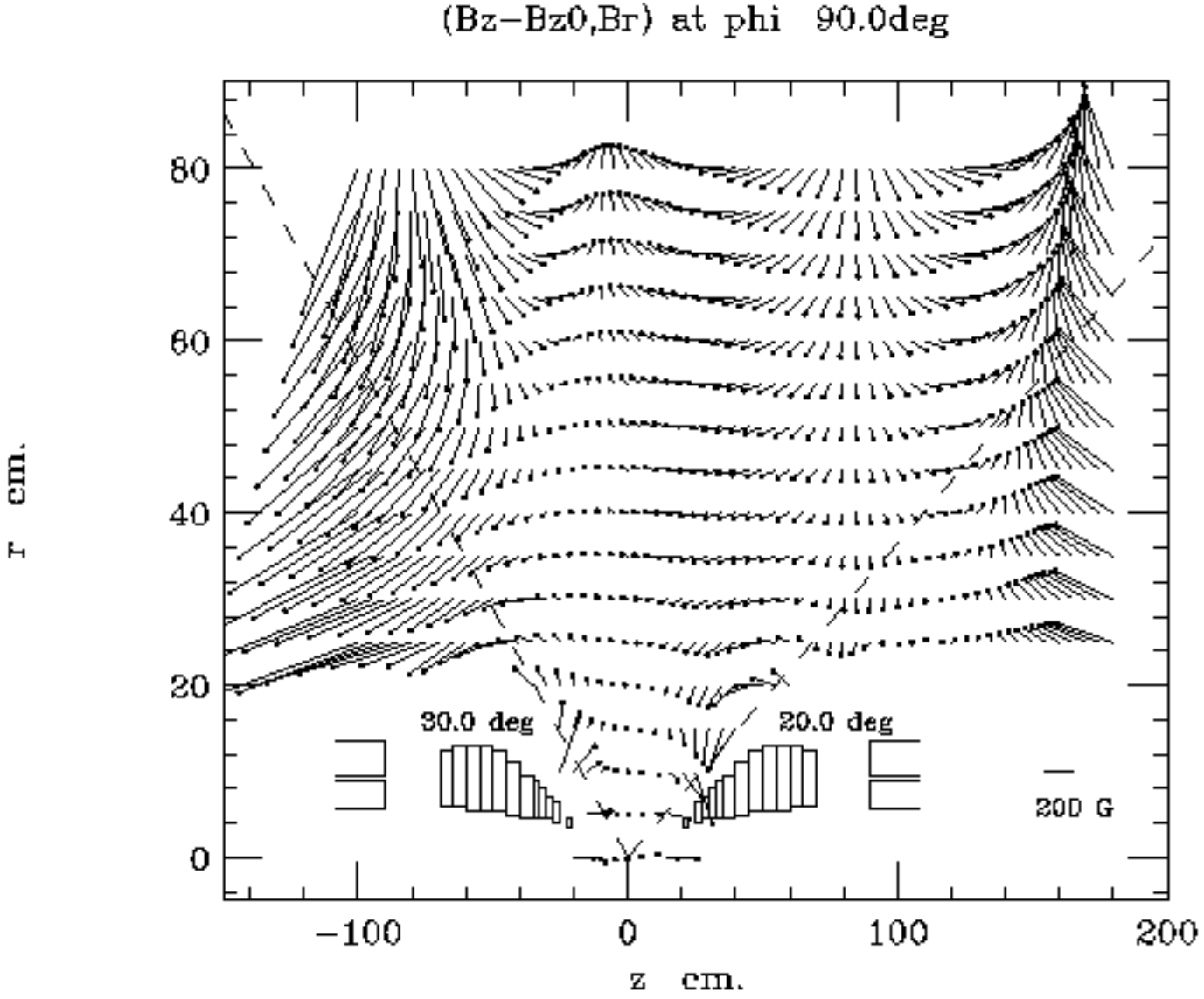
$$P'_{out\ (in)} = P_{out\ (in)} + (-)\ \delta P/\delta E \bullet \Delta E$$

$$C'_{out,in} = C_{out,in} + \underbrace{(\delta P/\delta E)^2\ \sigma_{\Delta E} + \left[(\delta P/\delta \Phi)^2 + (\delta P/\delta \Theta)^2\right] \sigma_{ms}}_{\equiv C_{mat}}$$



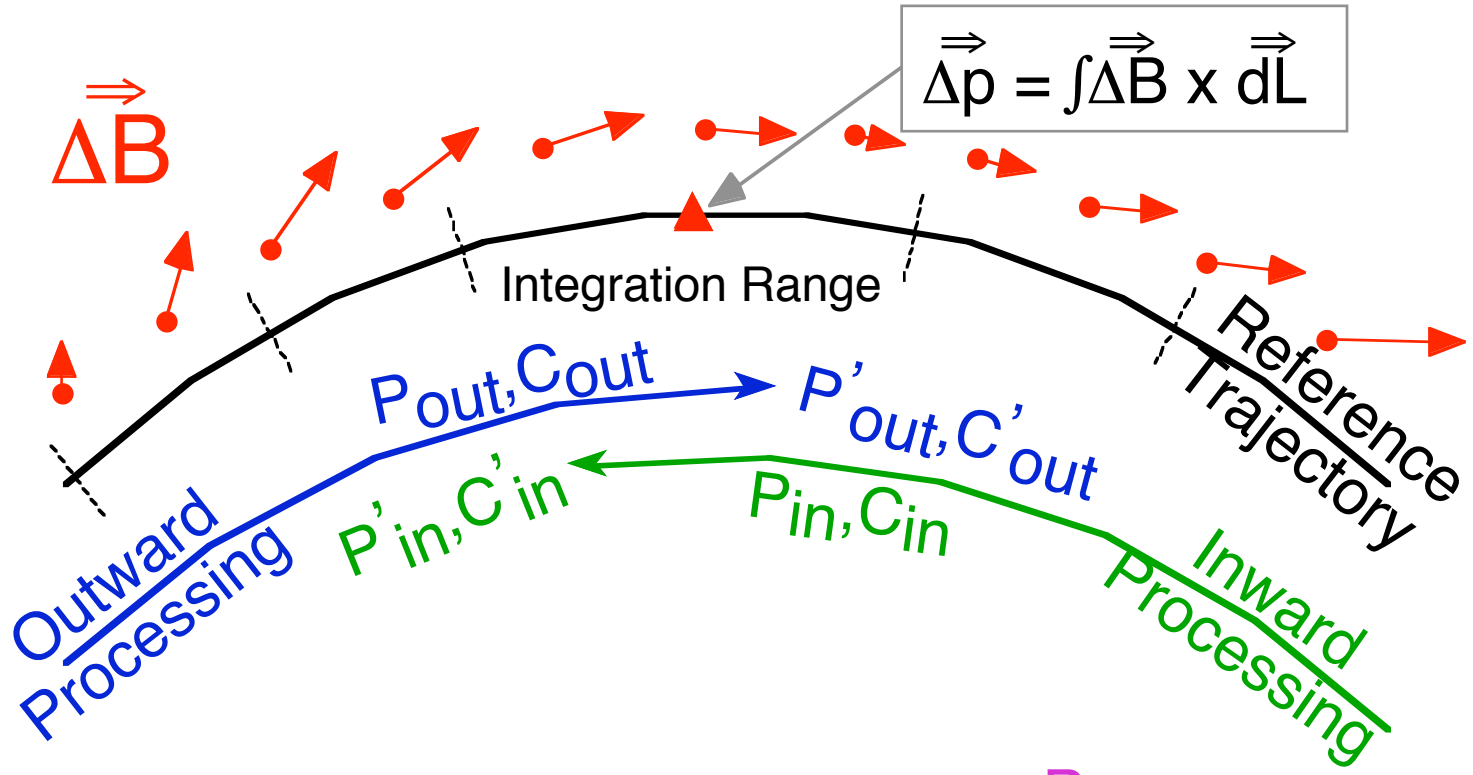
Extended material is divided into chunks, effect modeled at a point

BaBar Field Map



0→10 % effect on momentum direction and magnitude

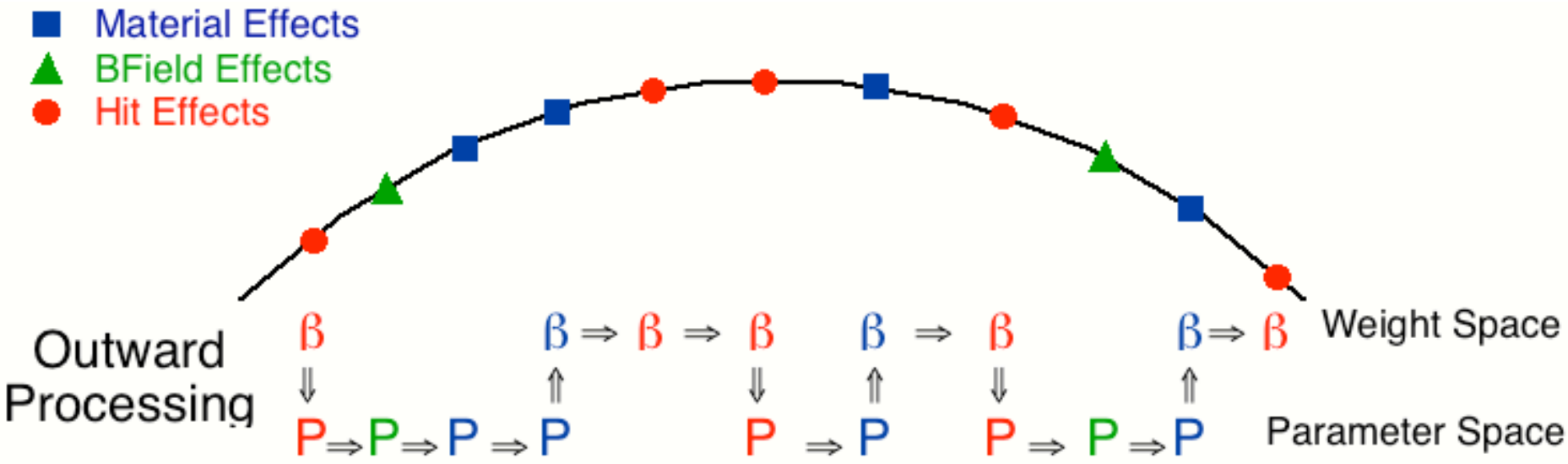
Magnetic Field Inhomogeneity Effect



$$P'_{out\ (in)} = P_{out\ (in)} + (-)\ \overbrace{\left[\delta P/\delta\Phi\ \Delta p_{\Phi} + \delta P/\delta\Theta\ \Delta p_{\Theta}\right]}^{\equiv P_B}$$

$$C'_{out,in} = C_{out,in}$$

Effect Processing



$\Uparrow, \Downarrow$ involve matrix inversion

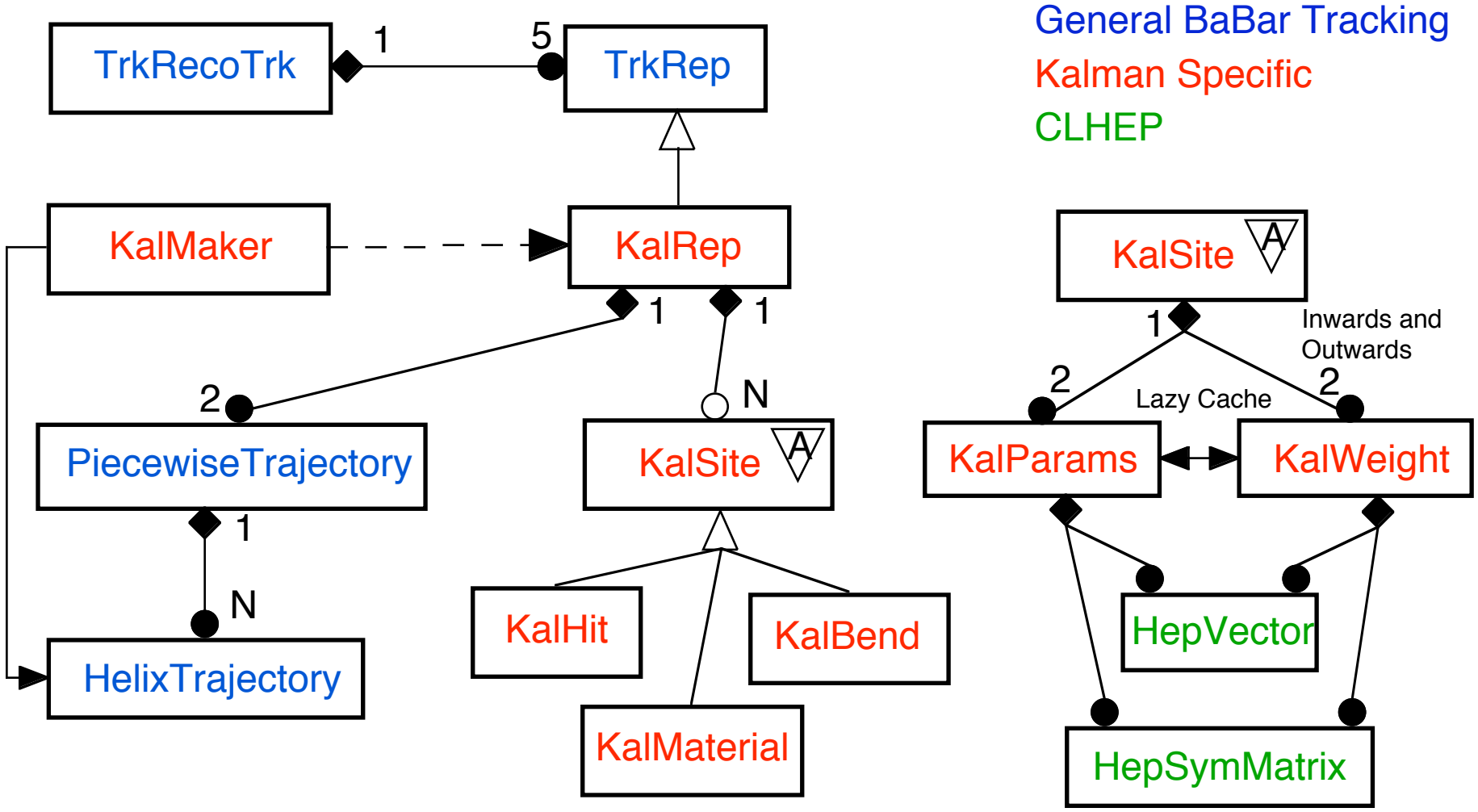
$\Leftarrow, \Rightarrow$ involve only linear operations

Optimal 'parameters' are easy to compute

$$\beta_{opt} = \beta_{out} + \beta_{in}$$

$$\gamma_{opt} = \gamma_{out} + \gamma_{in}$$

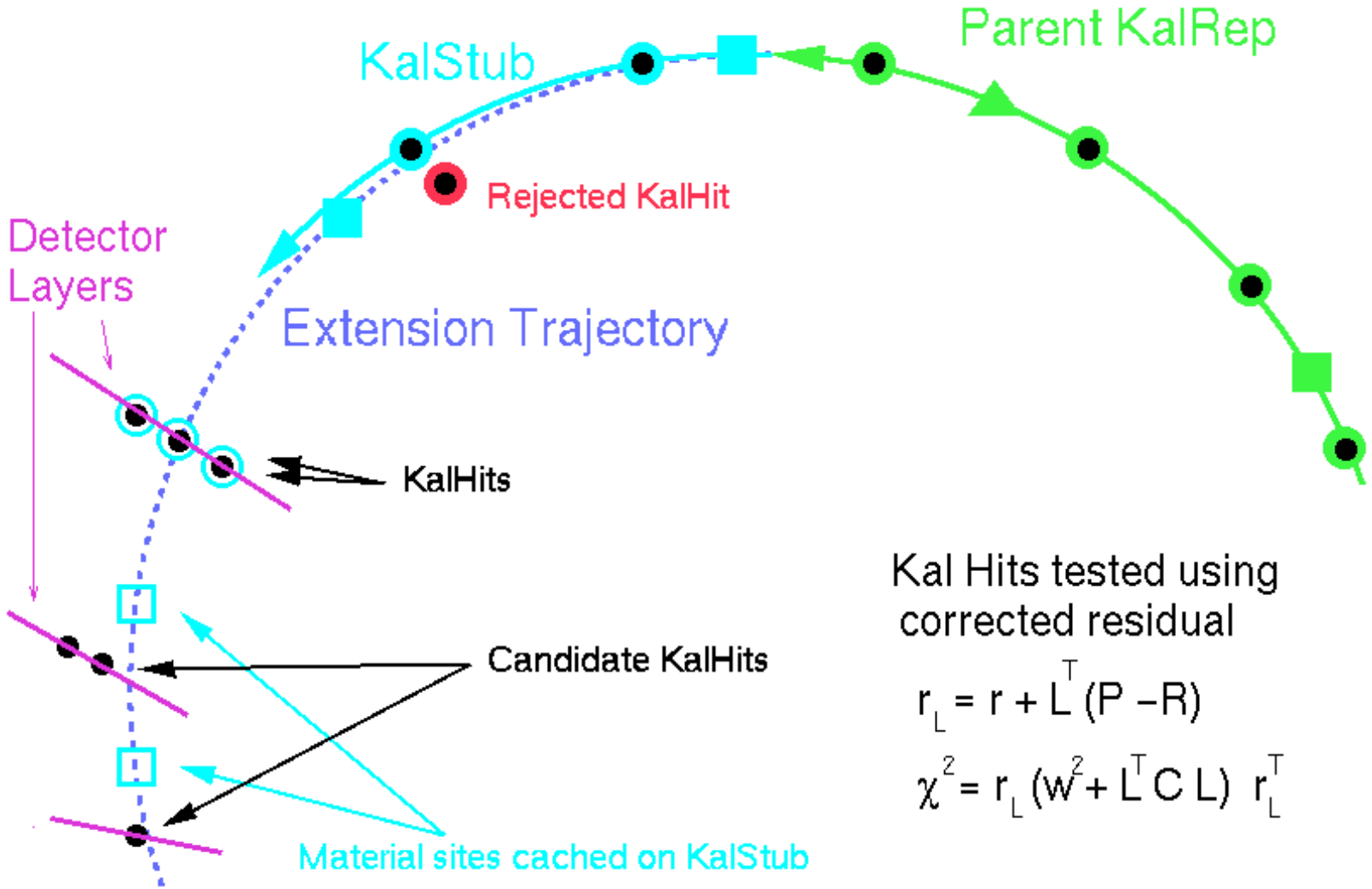
BaBar Kalman Fit Organization



Kalman Based Track Extension

- **The Kalman fit provides the optimal hit consistency measurement ($\Delta\chi^2$)**
  - ✦ **Includes all tracking environment effects**
- **Kalman formalism easily allows adding hits to the end of an existing track**
  - ✦ **Cost of 1 5X5 matrix inversion to compute χ^2**
  - ✦ **Exploits 'progressive' roots**
- **Additional Pat. Rec. infrastructure is needed**
  - ✦ **Hit pre-selection to reduce background**
    - ★ Road extrapolation
  - ✦ **Organize hits in coherent sets (segments, layers, …)**
  - ✦ **Allow multiple simultaneous competing solutions**
    - ★ Use 'future' information to help determine best hit choices
  - ✦ **Triage and arbitration for final choices**

KalStub: A Track Extension Tool

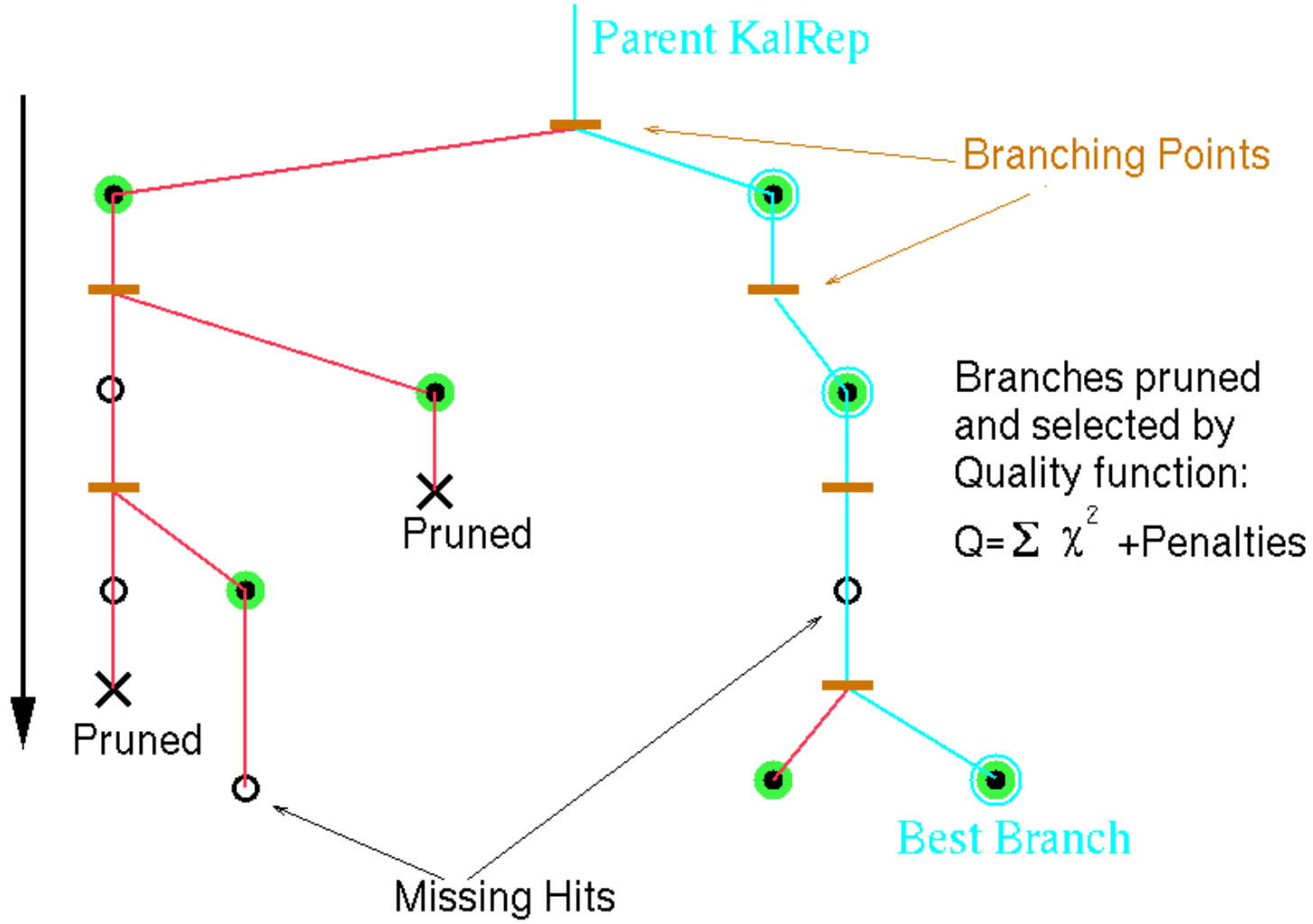


Kal Hits tested using corrected residual

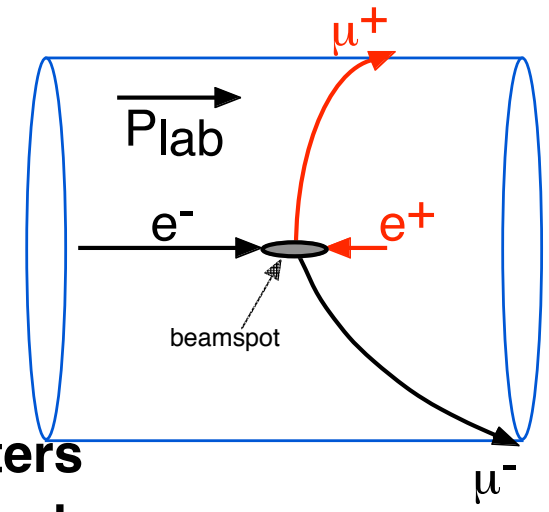
$$r_L = r + L^T (P - R)$$

$$\chi^2 = r_L (w^2 + L^T C L)\ r_L^T$$

Track Extension with KalStub



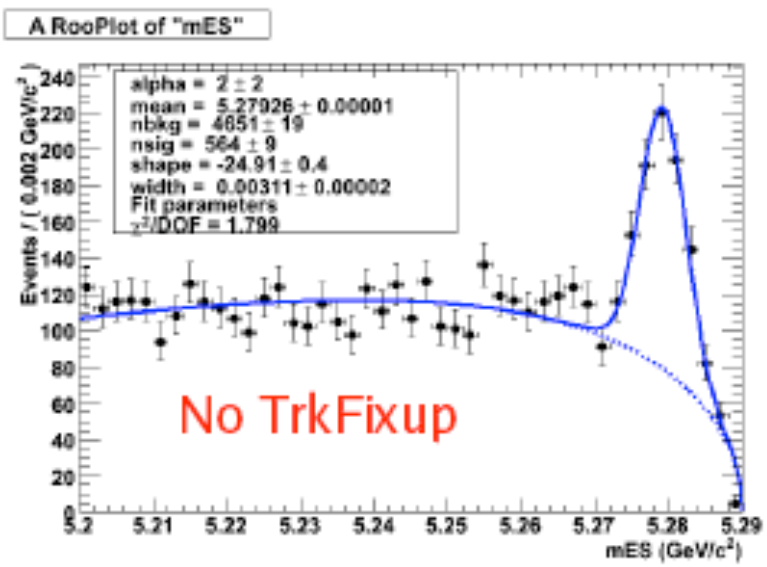
Other uses of BaBar Kalman Fit

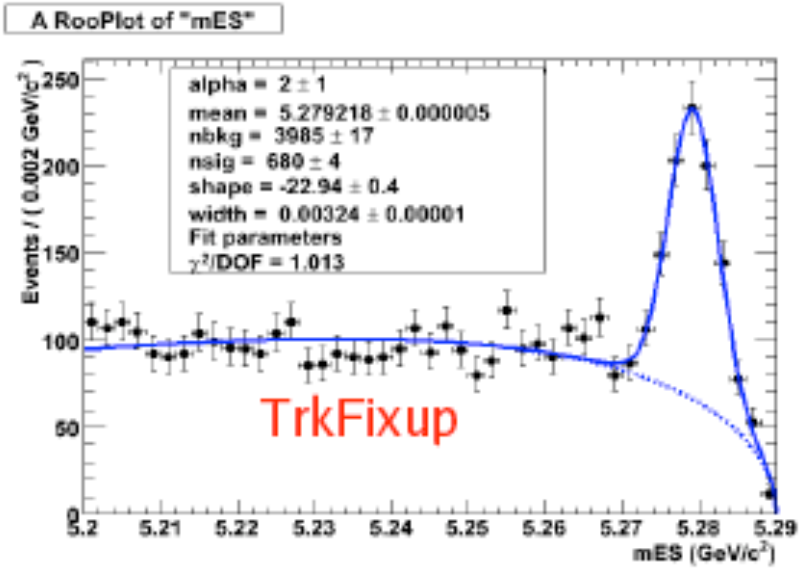


- **Tracking alignment**
  - ✦ **Interfaces for derivatives, residuals, …**
  - ✦ **$e^+e^- \rightarrow \mu^+\mu^-$ fit**
    - ★ Same formalism for any P_4-constrained fit
- **Track improvement**
  - ✦ **Brehmstrahlung recovery with Emc clusters**
  - ✦ **dE/dx momentum constraint in Si-only tracks**
- **Multi-layered persistence (root-based)**
  - ✦ **Full Kalman fit (mini)**
    - ★ Reconstitute materials, alignment, … on readback
  - ✦ **Fit summary**
    - ★ Fit parameters near origin, near
- **Physics interface**
  - ✦ **Kinematics, vertexing parameters**
- **Event display (WIRED) (full piecewise helix)**

TrkFixup: improving Tracks

- **BaBar mini allows improving tracks in analysis**
  - ✦ **Background removal**
    - ★ Ghosts, loopers, decays, material interactions, …
  - ✦ **Resolution improvement,**
    - ★ dE/dx con. on Si-only tracks,Bremstrahlung recovery, …
- **Physics 'skimming' with TrkFixup starts in July**
  - ✦ ***Inclusive B S/N increase from 0.79 to 1.14*** applying TrkFixup





Open Source Tracking Project

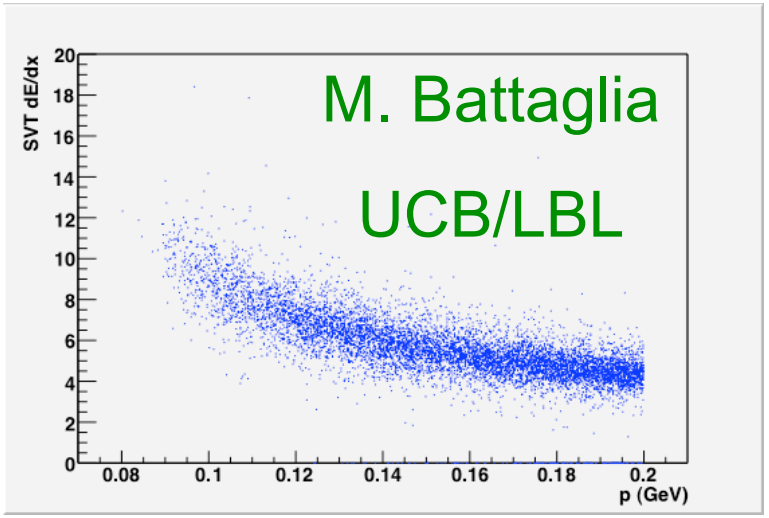
- **Goal**
  - **Create a repository for tracking code in HEP and related fields**
- **Purpose**
  - **Avoid duplication of effort and relearning in high-level algorithm development**
  - **Provide a means for tracking software collaboration across experiments**
- **Method**
  - **Refactorize software from existing HEP experiments and distribute through OpenSource**
- **Status**
  - **Funding proposal in consideration**
  - **Seed project (BaBar Kalman fit) in progress**

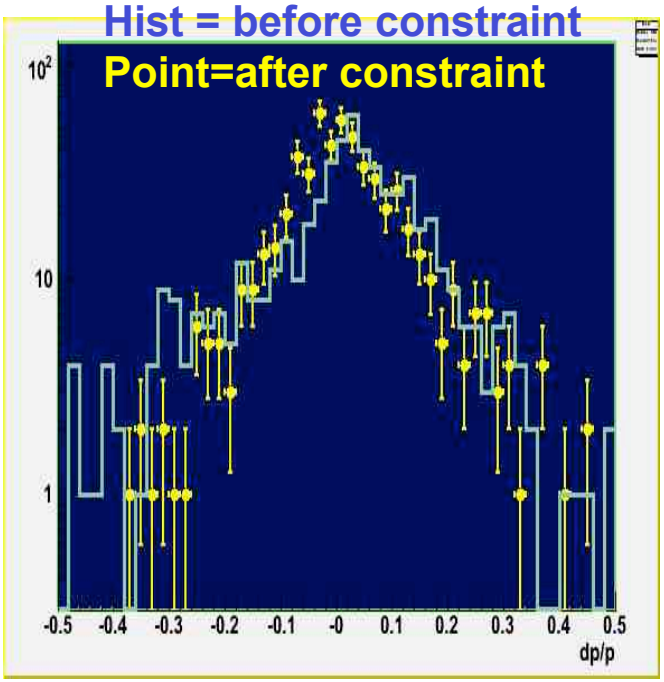
Conclusions

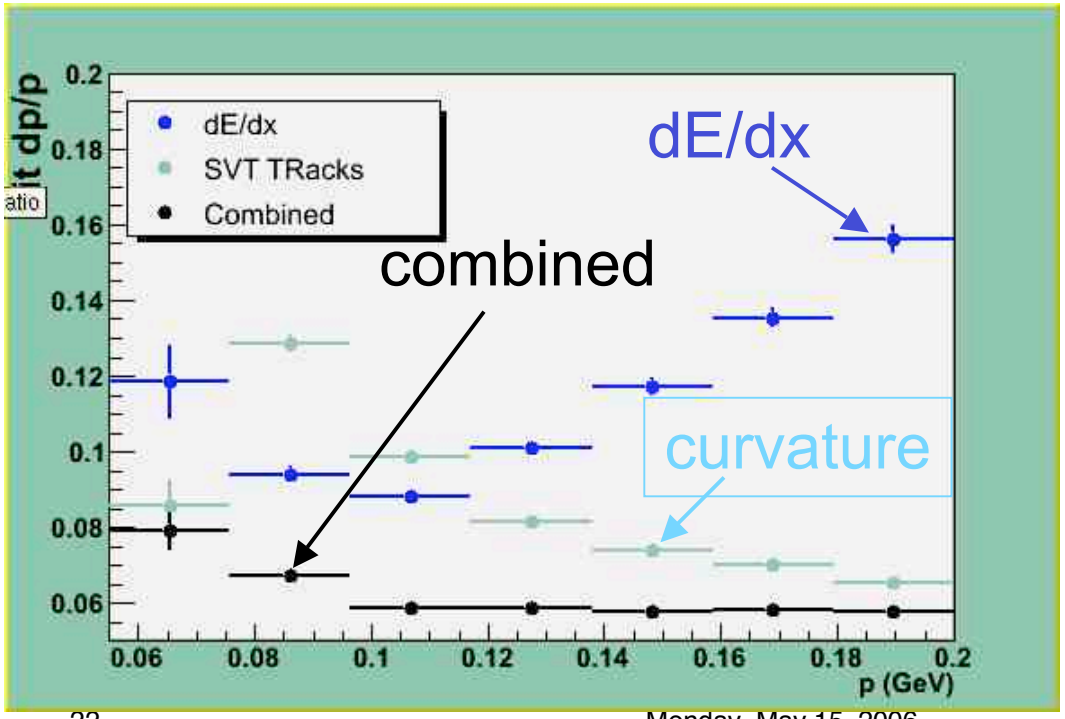
- **BaBar tracking is functioning for physics analysis**
  - **Sophisticated Kalman fit infrastructure**
  - **Extensive feature set**
  - **Battle tested**
- **Open source tracking project is starting**
  - **Seed on BaBar code**
  - **Outside collaborators are welcome**
- **References**
  - http://arxiv.org/pdf/hep-ex/0105044
  - http://www-zeuthen.desy.de/CHEP97/paper/341.ps
  - http://chep2000.pd.infn.it/abs/abs_a328.htm

dE/dx constraint

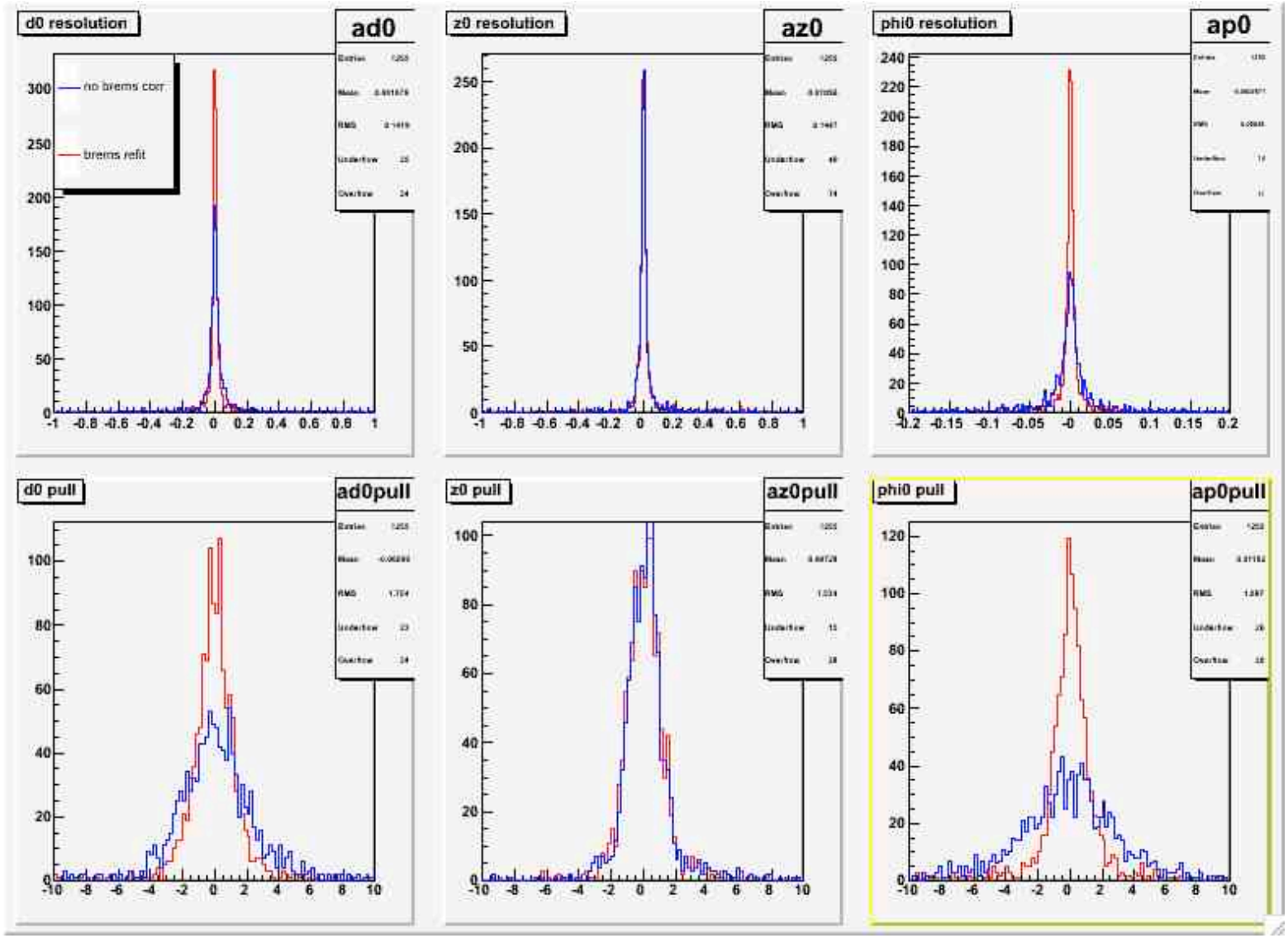
- **Idea: constrain momentum using (Svt) dE/dx by inverting B.B. curve**
- **Provides competitive P measurement as curvature at low momentum**
- **Makes $\delta P/P$ ~ flat vs P at <5%**
- **Reduces outlyers**
- **Need improved calibration of dE/dx to go below 90Mev**



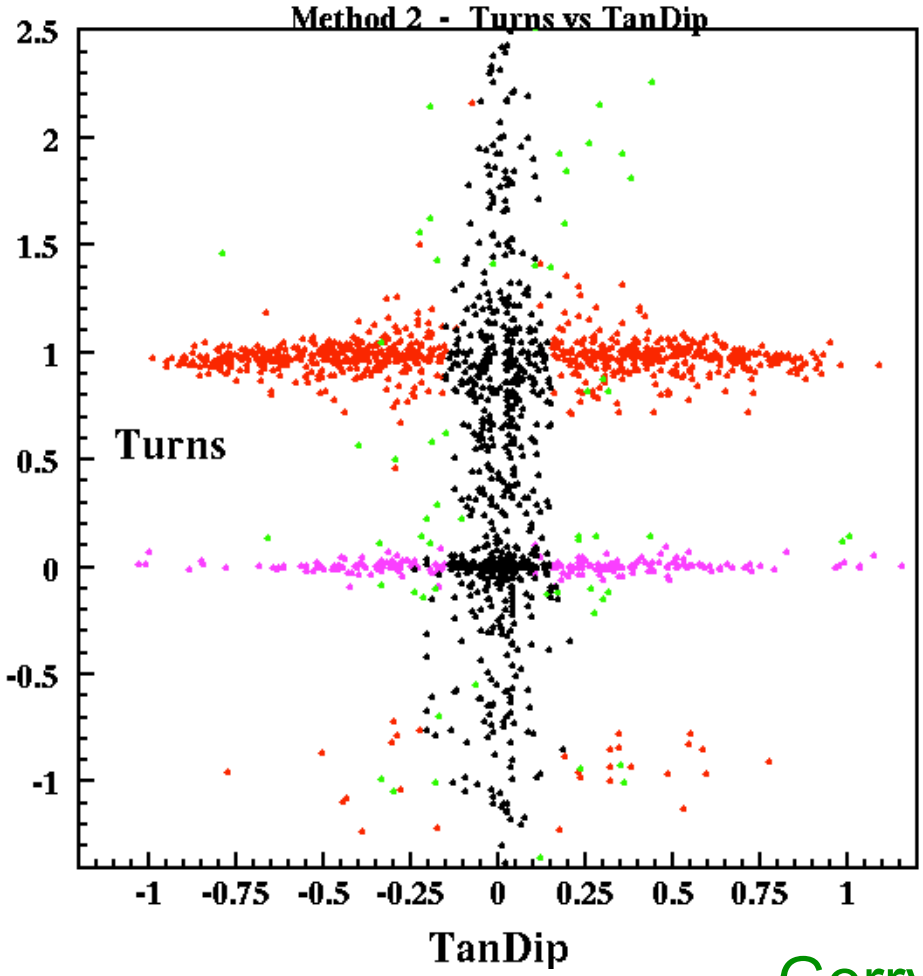


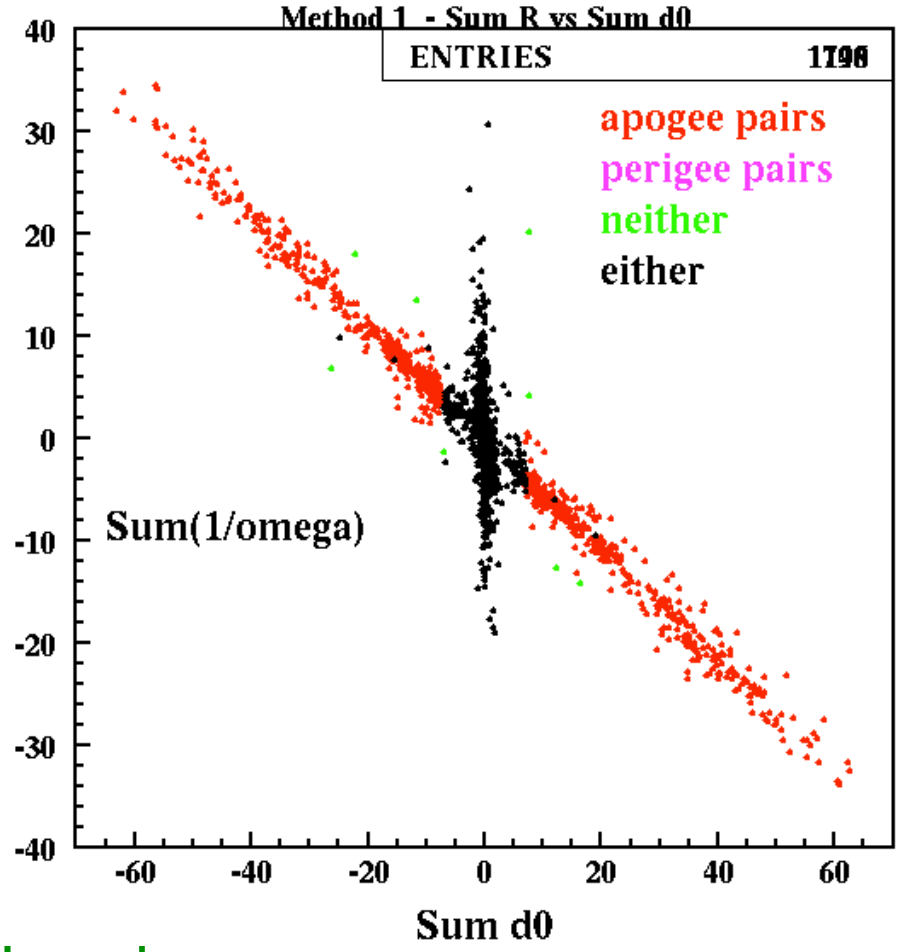


Bremsstrahlung Correction



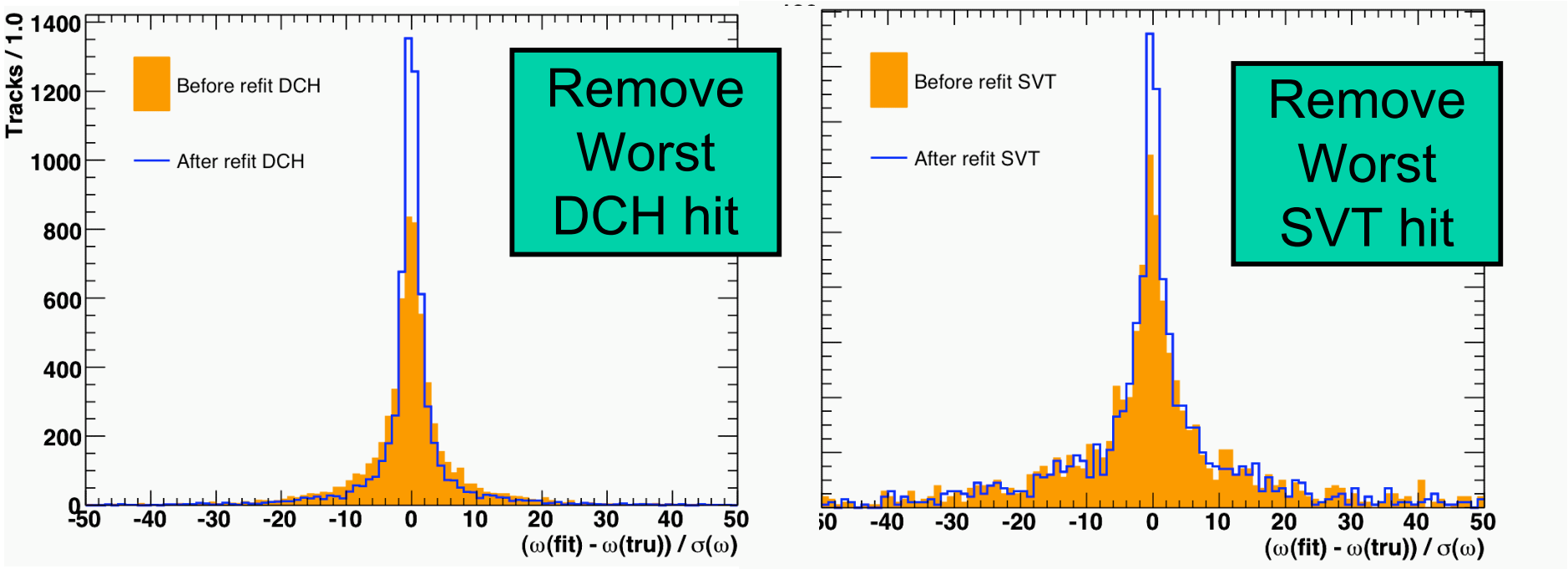
Which Looper Track is Primary?





Gerry Lynch

TrkHitFix Improves P_t resolution



$\omega \equiv 1/P_t$

LDRD specifics (1st year)

- **Start with BaBar track fit**
  - **OO C++, fully-featured, well understood locally**
- **Extract from BaBar, then adapt back to BaBar**
  - **Replace BaBar-specific dependencies with 'service adapters'**
  - **Compare performance with the original**
- **Simultaneously adapt to ILC (LDC)**
  - **Proves portability**
  - **Of immediate use in detector concept studies**
- **Focus on having working code early**
  - **Learn-by-doing**
  - **Involve external people ASAP**